United States
Department of
Agriculture

Forest Service

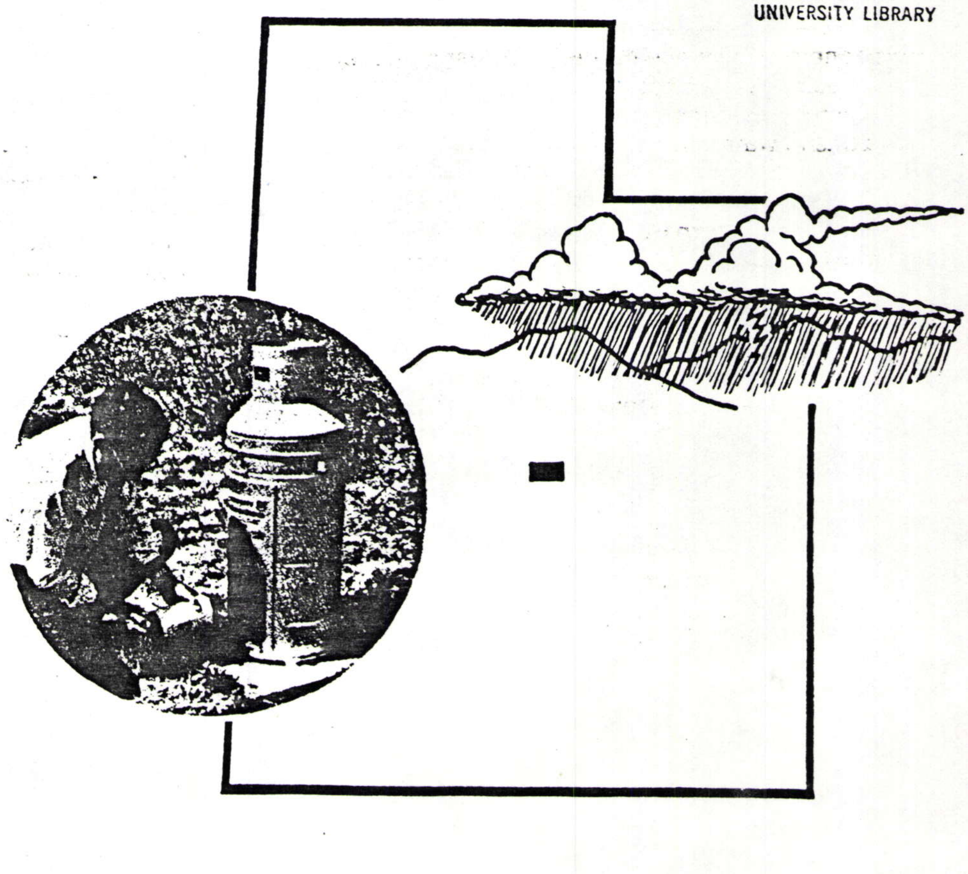
Intermountain
Forest and Range
Experiment Station

Research Paper
INT-274

May 1981

Precipitation Characteristics of Summer Storms at Straight Canyon Barometer Watershed, Utah

Joel E. Fletcher, A. Leon Huber, Eugene E. Farmer, Keith R. McLaughlin, John Rector, and Larry J. Schmidt



THE AUTHORS

JOEL E. FLETCHER, professor of hydrology—emeritus, Utah Water Research Laboratory, Utah State University, Logan, conducted water research with the U.S. Department of Agriculture in Tucson, Ariz.; Gallup, N. Mex.; Davis, Calif.; and Boise, Idaho. His principal interests have been rainfall-runoff relations, soils and instrumentation, before coming to Utah.

A. LEON HUBER, assistant professor, Utah Water Research Laboratory, conducted water research with the U.S. Department of Agriculture in Idaho before coming to Utah State University in 1961.

EUGENE E. FARMER, forest hydrologist on the Watershed Protection and Rehabilitation research work unit at Logan, Utah, joined the staff of the Intermountain Station in 1964. His primary investigations have been in the areas of mined land reclamation and hydrology and in mountain rainfall characteristics and soil erosion.

KEITH R. McLAUGHLIN is presently with the USDA Forest Service, Rocky Mountain Region, Medicine Bow National Forest, Laramie, Wyo., as a forest hydrologist. In his past 6 years with the agency, he has been assigned to the Cache and Manti-LaSal National Forests in Utah, respectively. He received a bachelor of science degree in forest watershed management from the University of Minnesota in 1970.

JOHN RECTOR is the forest hydrologist on the Manti-LaSal National Forest in Price, Utah. Previously, he has had assignments with the Tonto National Forest in Phoenix, Ariz., the Dixie National Forest, and Intermountain Region headquarters in Utah. He received a bachelor of science degree in forest management from Michigan Technological University, 1966, and a master of science degree from the University of Arizona in watershed management and soil physics, 1968.

LARRY J. SCHMIDT is presently with the Forest Service, Southwestern Region, Albuquerque, N. Mex., as regional hydrologist. In his past 10 years with the agency, he has been assigned to the Intermountain Region and to the Manti-LaSal and Toiyabe National Forests in Utah and Nevada, respectively. He received a bachelor of science degree in forest watershed management from Utah State University in 1967.

ACKNOWLEDGMENT

Precipitation data for this report were collected on the Straight Canyon barometer watershed, Manti-LaSal National Forest. The authors appreciate the cooperation of personnel on the Manti-LaSal National Forest for providing the data base. This watershed is part of a national program to tailor, apply, and demonstrate research-derived management prototypes in broad-scale forest management programs. This publication is part of the barometer program to characterize the hydrologic and climatic environment of the area.

RESEARCH SUMMARY

This paper presents results of data analyses for 10 precipitation intensity stations at Straight Canyon barometer watershed in central Utah located at elevations between 7,250 ft (2 210 m) and 10,400 ft (3 170 m) m.s.l. All data were collected between 1967 and 1974 during the months of May to October, with all records complete for July, August, and September.

The following analyses were made: (1) record consistency, (2) definition of local precipitation zones, (3) intensity-duration-frequency characteristics, (4) 24-hour precipitation depths, (5) monthly depths and numbers of storms, (6) storm occurrence by time of day, (7) storm occurrence by storm duration, (8) annual maximum erodent values for Straight Canyon gages, Davis County experimental watershed, and Great Basin experimental area. The precipitation zone between 7,000-8,000 ft (2 134 - 2 438 m) m.s.l. is expected to receive the highest rainfall intensities. Rainfall intensity decreases with elevation. The zones receiving the greatest rainfall receive the lowest intensities. The major portion of storms occur between the hours of 11:00 a.m. and 3:00 p.m. Eighty percent of the storm have durations shorter than 2.8 hours, with the highest elevations having the shortest durations. Erodent values are inversely proportional to the elevation and penetration past the uplift barrier. The use of erodent values is described.

CONTENTS

United States
Department of
Agriculture

Forest Service

**Intermountain
Forest and Range
Experiment Station**

Research Paper
INT-274

May 1981

Precipitation Characteristics of Summer Storms at Straight Canyon Barometer Watershed, Utah

Joel E. Fletcher, A. Leon Huber, Eugene E. Farmer, Keith R. McLaughlin, John Rector, and Larry J. Schmidt

INTRODUCTION

Precipitation records in high mountain areas are scanty. In Utah and the balance of Western United States nearly all of the rainfall intensity gages are located at elevations below 6,000 ft (1 829 m) m.s.l. Even in the valleys most of the recording rain gage records have not been reduced except by hours.

The papers of Farmer and Fletcher (1971, 1972a, 1972b), Chang (1969), and Croft and Marston (1950) have been given considerable insight into the characteristics of high mountain, short-burst rainfall events. Miller and others (1973) improved the isohyetal maps of the Western United States and included regressions for determining short duration expectancies from those for 6 hours for returns between 2 years and 100 years.

Personnel of the Utah Water Research Laboratory and Intermountain Forest and Range Experiment Station (1976) developed annual isoerodent maps of the United States including the Mountain States, in order to extend the universal soil loss equation to all areas of the country. As a consequence of the availability of these maps, the use of isoerodent values for runoff peak forecasting was tested and the annual isoerodent values were found to be the most pertinent precipitation parameter for forecasting runoff peaks from ungaged watersheds (Fletcher and others 1976).

This paper presents an extension of Farmer and Fletcher (1971) to include 10 precipitation gages of the Straight Canyon barometer watershed area and the isoerodent values for the Straight Canyon area, the Davis County area, and the Great Basin experimental area.

All precipitation gages were operated during June through September and four were operated from April through October. Gages were at elevations ranging from 7,235 ft (2 205 m) m.s.l. for the Orange Olsen site to 10,400 ft (3 170 m) m.s.l. for the Skyline site. The gages were sufficiently close to one another that single storms were frequently recorded on more than one precipitation gage.

The Straight Canyon barometer watershed is located 12 miles W.N.W. of Orangeville, Utah, immediately adjacent to the Great Basin experimental watershed. It lies up the left fork of Cottonwood Creek and occupies an area of about 145 square miles. Elevation ranges between 6,852 ft (2 088 m) and 11,300 ft (3 444 m) m.s.l. The description given by Farmer and Fletcher (1971) of the Great Basin experimental area is also applicable to the Straight Canyon barometer watershed.

Total annual rainfall ranges from 16.10 inches (40.89 cm) at Lower Joes Valley to slightly over 40 inches (102 cm) on the three peaks (U.S. Weather Bureau 1967). Approximately 44 percent of the precipitation falls during the period May to September.

Summer precipitation contributes little water to the annual stream flow volume, but it is important to the production of mountain vegetation that is vital to soil stability (Packer 1951; Orr 1957; Packer 1963; and Croft and Bailey 1964). however, vegetal cover is only one factor that affects the hydrologic performance of a watershed. Storm characteristics also have a major effect on the processes of soil erosion and flood production, especially when the land becomes barren of vegetal cover due to fire, road construction, overgrazing, or urban development.

A storm was defined for this study as a period of precipitation, uninterrupted for a period exceeding 1 hour, delivering at least 0.10 inch (2.5 mm) of water. Most of these storms were convective thunderstorms and frontal thunderstorms aided through orographic lifting. Summer convective cells, often associated with lightning, usually approach from the south or southwest, which is the direction of the prevailing wind of that season. Some of the storms that delivered the greatest intensity of rainfall were probably of a type that has been termed orographic-convective. The primary source of summer moisture aloft comes from the Pacific Ocean (Hales 1972, 1973). A small proportion of the total storms comes from large frontal systems.

Summer convective storms delivering very high-intensity rainfall have been the source of destructive debris floods. Summer debris floods emanating from the Wasatch Range were particularly destructive (Bailey and others 1934; Bailey and other 1947). These summer-flood flows took lives, destroyed property, and disrupted communities.

METHODS

Machine methods were used to digitize the original analog rainfall records. Compilation of the digitized records was done by computer. The final computer output for every storm consisted of both accumulated precipitation depth and rainfall intensity for the following 12 time durations: 2, 5, 10, 15, 20, and 30 minutes and 1, 2, 4, 6, 12, and 24 hours. The computer output also included the total precipitation depth for every month as well as a yearly summary of maximum depth and intensity.

Record Consistency

All of the records were checked for consistency by double-mass plotting (Searcy and Hardison 1960). This technique was applied to the combined depth records only for July and August because all of the gages were in operation during these months.

Frequency Analysis

A detailed annual series frequency analysis of rainfall intensity was made for every station. A separate analysis was made for each of the 12 time durations. The formula developed by Weibull was used to obtain plotting positions (Chow 1964):

$$T = \frac{n+1}{m}$$

where

T = recurrence interval, years
n = number of years of record
m = order number of the items arranged in descending order.

This formula has been found to be theoretically suitable for plotting annual maximum series on extremal distribution paper (Chow 1953).

Table 1.—Listing of precipitation intensity stations, Straight Canyon barometer watershed

Station	Location, fig. 1	Precipitation zone number	Period of record	No. of years	Elevation
					Feet
Horn Mountain	1	1	1967 - 1974	8	9,275
Bubs Meadow	2	1	1967 - 1974	8	8,150
Wagon Road Ridge	3	2	1967 - 1974	8	10,100
Seely Guard Station	4	1	1967 - 1974	8	8,990
Swasey Ridge	5	2	1967 - 1974	8	10,030
Skyline	6	1	1967 - 1974	8	10,400
Lower Black Canyon	7	3	1967 - 1974	8	7,765
Central Weather Station	8	1	1967 - 1974	8	9,020
Orange Olsen	9	1	1967 - 1974	8	7,235
Scad Valley	10	1	1967 - 1974	8	9,160

Table 2.—Average properties of the precipitation zones of Straight Canyon barometer watershed

Precipitation zone	Average elevation	Average I_{10}/I_2	Average penetration	Average R	Average R_{10}/R_2	Vegetation type
	Feet		*Miles*			
1	8,890	1.98	29.1	12.5	3.8	Conifer-aspen
2	10,065	3.11	26.7	13.9	8.1	Grass
3	7,765	2.98	27.7	16.7	4.1	Grass-sage

Precipitation Zones

Peck and Brown (1962) divided Utah into 20 precipitation regions. They found that a large amount of the variation between regions in the May-September precipitation was accounted for by elevation. All of our data are point data. Consequently, we had to define criteria for dividing the study areas into homogeneous zones in order to make areal application of these point data.

The three criteria used were: (1) station elevation; (2) the values from the station intensity-duration-frequency curve; and (3) the station I_{10}/I_2 ratio for all durations between 2 and 30 minutes (fig. 1, tables 1 and 2). The latter is a dimensionless ratio that expresses the average slope of the short-duration rainfall intensity curves between 2 and 10 years. This ratio was computed by dividing the summation of intensities having durations of 2, 5, 10, 15, 20, and 30 minutes for the 10-year recurrence interval by the comparable summation for a recurrence interval of 2 years. Any region that is homogeneous with respect to its rainstorm characteristics should have frequency curves of about equal slope or steepness. Consequently, the I_{10}/I_2 ratio is useful statistic for comparing the slopes of frequency curves as a basis for judging homogeneity of precipitation zones.

24-Hour Precipitation Depth

The intensities for the 24-hour duration were converted to precipitation depths for recurrence intervals of 10, 25, and 50 years. Twenty-four hours was the longest duration examined in this study.

Average Monthly Depth and Number of Storms

Analyses for the average monthly depth of precipitation and the average number of storms per month are complete only for June-September. At the highest elevation stations, the data for May and October were insufficient to compute a reliable monthly average.

Storm Occurrence by Hour

Storm occurrence by hour was analyzed by compiling the number of storms starting in any hour of the day expressed as a percent of the total storms. These data were plotted as a mass curve for each zone.

Storm Penetration

Storm penetration is a measure of the distance a storm travels downwind from the first uplift barrier, in this case the Wasatch and Pavant Mountain Ranges. The greater the penetration, the less precipitation falls at a given elevation.

Erodent, R, Values

The erodent values for each precipitation station were calculated from the unit intensity and volume by the relationship:

$$EI = \sum_{O}^{yr} \left(\frac{916 + 331 \log I}{100} \times P \right) \times I_{30}$$

where

EI = rainfall erosivity index for 1 year or other period

I = rainfall intensity for a short unit of time

P = volume of precipitation in the same unit of time

I_{30} = the annual maximum, or other period as for EI, 30-minute rainfall intensity

R = the mean annual EI value as derived from a frequency plot of annual EI values. (See Wischmeier and Smith 1958.)

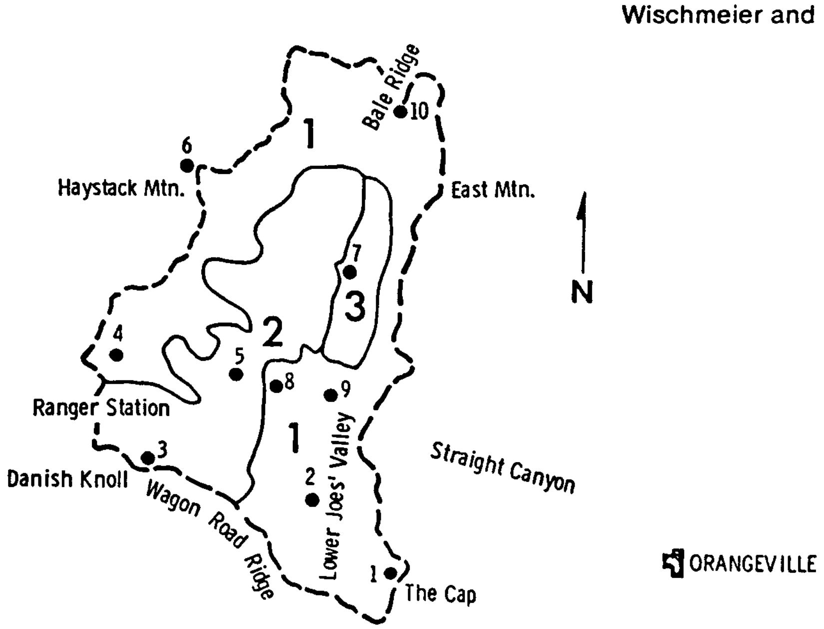


Figure 1.—Map of Straight Canyon barometer watershed Utah, showing zones and gages.

Storm Duration

The duration of all storms at all precipitation gages was divided into 0.25-hour units and the frequency in each group recorded and expressed as a percentage of the total number of storm events. These percentages were plotted against the unit of duration in which each occurred.

RESULTS

Consistency Test

The records were not adjusted. None of the mass curves plotted as smooth straight lines and isolated points fluctuated both above and below the trend line. Even so, the breaks in the lines didn't persist for a period as long as 5 years. The breaks in the lines were considered to be no greater than might reasonably be expected for thunderstorm data obtained from mountainous areas. Furthermore, none of the differences between the first and second half of the records were significant so the records could be said to be consistent.

Precipitation Zones

Within the study area the precipitation zones are related to the vegetal patterns (table 2), as was noted by Farmer and Fletcher (1971), even though the contrasts in vegetal types are not as great at Straight Canyon as on the Davis County or Ephraim watersheds.

Intensity-Duration-Frequency Characteristics

The curves in figures 2, 3, and 4 are for recurrence intervals of 2 to 50 years and storm durations between 2 minutes and 24 hours. All return period intensity values for 10 years and longer were determined by linear interpolation. As such, these must be used with caution. Also, the recurrence interval is the average interval during which an intensity of a given duration will recur as an annual seasonal maximum.

Snow may have occurred during any month of the year at the higher elevations, and thus was probably caught in all of the higher elevation gages. There is little doubt, however, that values for periods shorter than 2 hours and recurrence intervals longer than 10 years are from rainfall events.

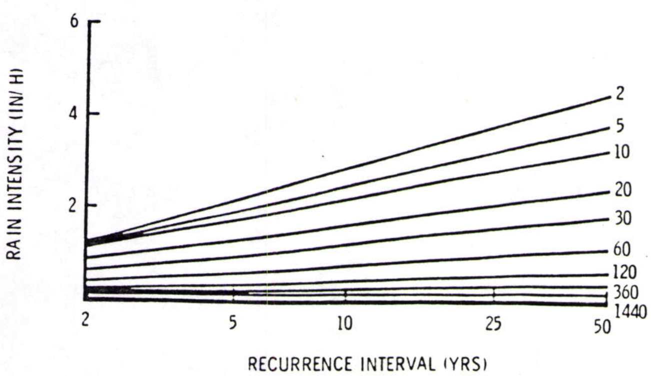


Figure 2.—Rainfall intensity-duration-frequency curves for Straight Canyon barometer watershed, Utah, zone 1.

The rainfall intensities in each precipitation zone are appreciably different from those in any other zone. For example, for a duration of 2 minutes and 2-year recurrence, the intensity is 1.20 in (30 mm)/h for zone 1, 0.30 in (8 mm)/h for zone 2, and 1.65 in (4.2 mm)/h for zone 3. At a 50-year recurrence, the 2-minute intensities become 4.52 in (118 mm), 7.65 in (194 mm), and 13.50 in (343 mm)/h, respectively. The 50-year/2-year ratios for a 2-minute duration become 3.77 in (96 mm), 25.5 in (648 mm), and 8.18 in (208 mm)/h for zones 1, 2, and 3, respectively.

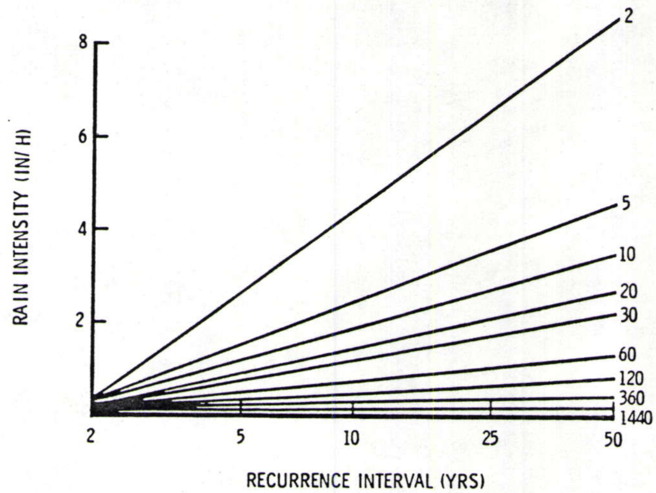


Figure 3.—Rainfall intensity-duration-frequency curves for Straight Canyon barometer watershed, Utah, zone 2.

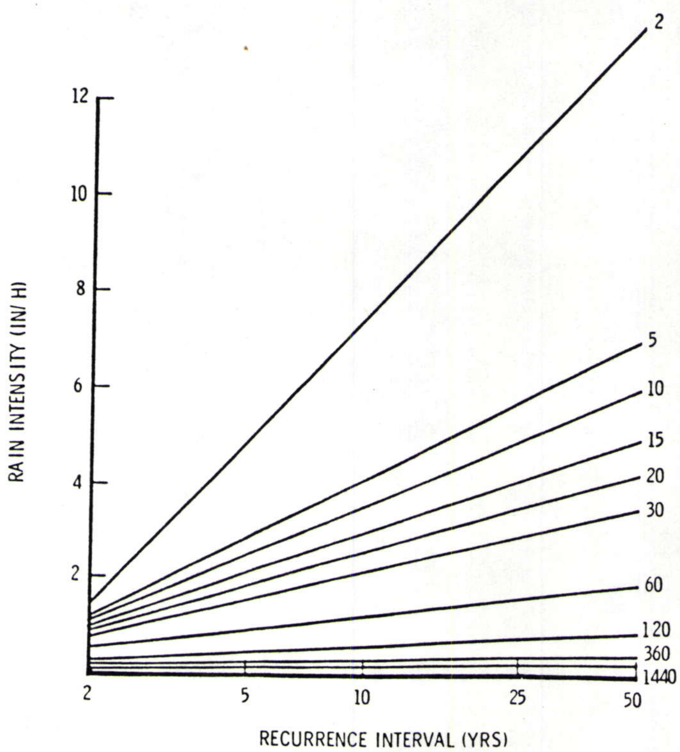


Figure 4.—Rainfall intensity-duration-frequency relationship curves for Straight Canyon barometer watershed, Utah, zone 3.

24-hour Precipitation Depth

Only 4 percent of the storms at the Straight Canyon barometer watershed have durations longer than 7 hours. However, the longer duration storms are of interest in the design of contour trenches and road drainage devices. Storms of long duration rarely produce floods in this area.

The 24-hour volumes were tabulated for the three zones for recurrences of 10, 25, and 50 years and are presented in table 3. As would be expected, considering the penetration distance from the mountain front the 14-hour precipitation volumes are smaller than the volumes for either Davis County or Ephraim experimental areas.

Average Monthly Depth and Number of Storms

The monthly precipitation depths were determined from gage catch. We hoped that these data could assist in clarifying the mountain-valley precipitation relationships when used in conjunction with intensity-duration-frequency characteristics.

Monthly precipitation fluctuates widely between zones and between years. Any month during the period May-October may be completely dry at one or more precipitation stations. Also, any month may exceed the average threefold to sevenfold.

The average number of storms during each month and within each zone varies widely as does the monthly volumes of precipitation (table 4). These values resemble those for the Great Basin experimental area (Farmer and Fletcher 1971). The expected relation between a valley station, Castle Dale, was of a relatively low order. Furthermore, the most intense rains occurred in zone 3 while the greatest monthly volume fell in zone 2. This distribution confirms the significant correlation between elevation and monthly rainfall volume. Figure 5 illustrates the seasonal precipitation volumes for the three zones and Castle Dale, which is in the valley just below Straight Canyon barometer watershed. Indications with these incomplete data confirm the September dry season mentioned by Price and Evans (1937) for the Great Basin experimental area, but certainly there is no dry spot in June although the summer season does appear to be bimodal. Our analysis shows a low precipitation volume for July and September at Straight Canyon barometer watershed as well as at Ephraim experimental area and Davis County experimental watershed.

Table 3.—Expected annual seasonal maximum 24-hour precipitation depths (inches) by precipitation zones and recurrence intervals

Zone	Recurrence interval (years) 10	25	50
		Straight Canyon barometer watershed	
1	1.50	1.83	2.08
2	1.48	1.79	2.03
3	1.37	1.70	1.97
		Davis County experimental watershed	
1	2.21	2.54	2.74
2	2.04	2.38	2.45
3	1.44	1.87	2.11
4	1.54	1.87	1.97
		Great Basin experimental area	
1	1.15	1.30	1.34
2	1.49	2.16	2.47
3	1.70	2.16	2.33
4	1.39	1.66	1.70

Table 4.—Precipitation depth (inches) and number of storms by month and zone, Straight Canyon barometer watershed

Month	Zone 1 Depth	Zone 1 Number	Zone 2 Depth	Zone 2 Number	Zone 3 Depth	Zone 3 Number
July	1.17	5.4	1.46	5.2	1.10	6.1
August	1.25	7.9	1.57	10.3	1.18	8.0
September	0.81	3.1	0.74	3.9	0.70	2.3

The summer precipitation burst is considered to be a reflection of the summer Gulf of California monsoonal storms as well as orographic convection. The monsoonal storms generally peak during August but may occur in the period June through October.

Storm Occurrence by Hour

On the average, storms occur on the Straight Canyon barometer watershed most frequently between 1100 and 1300 hours. Figure 6 shows the percentage of storms occurring during each period of the 24-hour day. Note that few storms occur between 2100 and 900 hours. This observation agrees with the distributions found on the Great Basin experimental area (Farmer and Fletcher 1971). Both these curves differ significantly from the curves for Davis County.

The concentration of the storms in the afternoon is expected because convection must trigger the monsoonal storms as well as orographic convective storms.

Storm Penetration

The storm penetration distances in miles downwind from the Wasatch-Pavant fronts for each gage on the Straight Canyon barometer watershed are shown in table 2. A good, simple correlation with a log-log transform exists between the miles of penetration and 10-year, 10-minute precipitation intensity. The correlation coefficient, $r^2 = 0.59$, is significant at the 1 percent probability. When all gages are included in the relationship, the gages on the windward slopes dominate the relationship and the correlation reverses to become significantly negative at the 5 percent probability level.

Within Straight Canyon the 10-year, 10-minute rainfall intensity increases from 1.55 in (39 mm) to 2.85 in (72 mm) per hour as penetration increases from 20 to 30 miles. On the other hand when all three locations are in the regression, the 10-year, 10-minute precipitation intensity decreases from 3.00 in (76 mm) per hour at 0.7 miles to 2.30 in (58 mm) per hour at 30 miles.

Erodent Values, R

The mean annual EI values for the three locations may be seen in tables 2 and 5 for each of the precipitation zones. Since R values are determined from log probability plots of the annual EI values, it is important to know not only the R or mean annual (2-year) EI value but the slope of the line that was used in the rainfall frequency depth curves. The ratio of the 10-year EI value to the 2-year (R_{10}/R_2) gives this slope. Then an EI value for any frequency greater than the mean annual value (R_2) can be determined.

For periods of time shorter than 1 year the curves as a percentage of the mean annual R value are of use. Figure 7 shows the monthly percentage of the annual R value that occurs from the beginning of the season to each date to the end of the season for each of the three precipitation zones of the Straight Canyon barometer watershed. Figure 8 shows the same data for the Great Basin experimental area zones and figure 9 shows the same data for the Davis County experimental watershed zones.

Use of R Values

Wischmeier and Smith (1958) presented a method for utilizing the R value as a parameter for estimating mean annual erosion east of the Rocky Mountains. Utah State University and Intermountain Forest and Range Experiment Station (1976) extended the procedure to

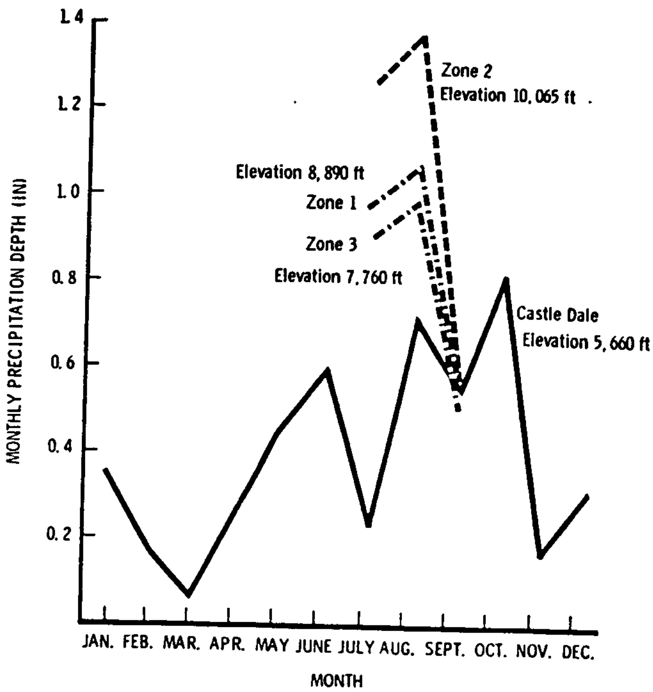


Figure 5.—The mean monthly precipitation depths for Straight Canyon barometer watershed zones 1, 2, and 3 and Castle Dale, Utah

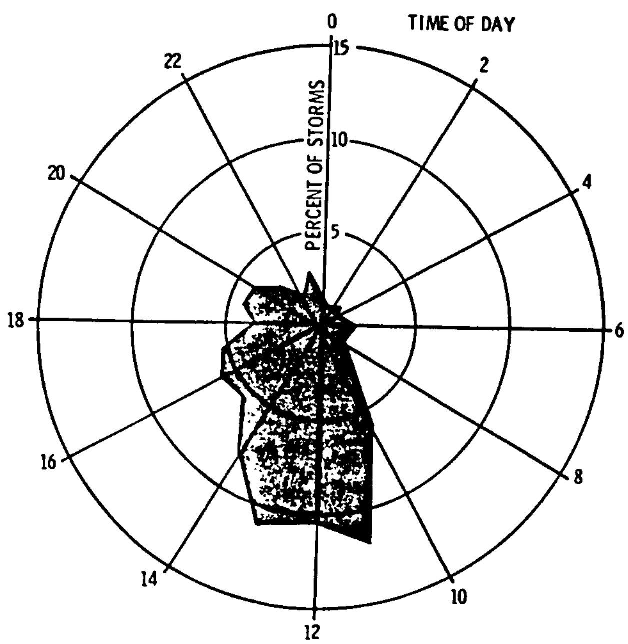


Figure 6.—The frequency distribution of storms by hour of the day at Straight Canyon barometer watershed, Utah.

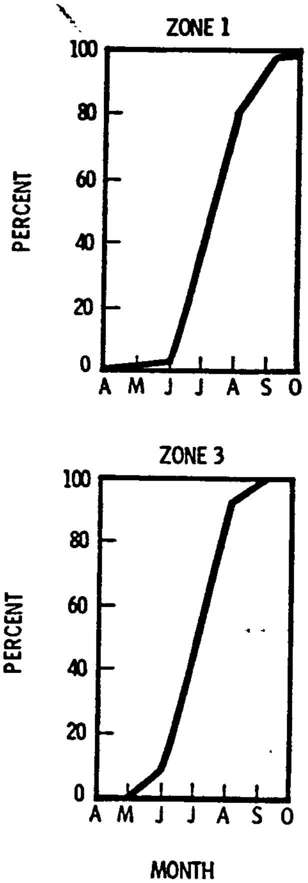


Figure 7.—The monthly erodent or rainfall erosivity values as a percentage of R for zones 1, 2, and 3 of Straight Canyon barometer watershed, Utah.

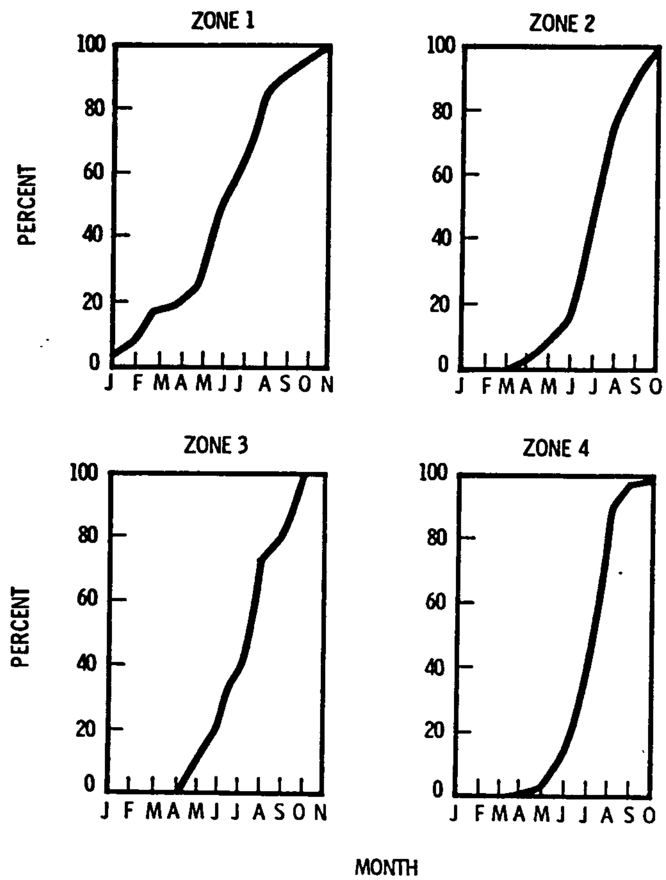


Figure 8.—The monthly erosivity values as a percentage of R for zones 1, 2, 3, and 4 for the Great Basin Experimental Area, Utah.

Table 5.—R values by precipitation zone for Davis County experimental watershed and Great Basin experimental area

Zone	Vegetation	R	R_{10}/R_2	I_{10}/I_2	Mean elevation
					Feet
		Davis County experimental watershed			
1	Oak brush	15.5	5.7	1.87	4,350
2	Aspen-fir	19.4	4.2	1.94	6,930
3	Spruce-fir	14.5	4.6	2.30	8,380
4	Spruce-fir	9.6	5.4	2.49	8,760
		Great Basin experimental area			
1	Pinyon-juniper	24.8	9.0	2.35	5,550
2	Oak brush	11.1	3.9	3.16	7,650
3	Aspen-fir	20.0	5.2	1.73	8,850
4	Spruce-fir	16.6	3.4	2.25	9,850

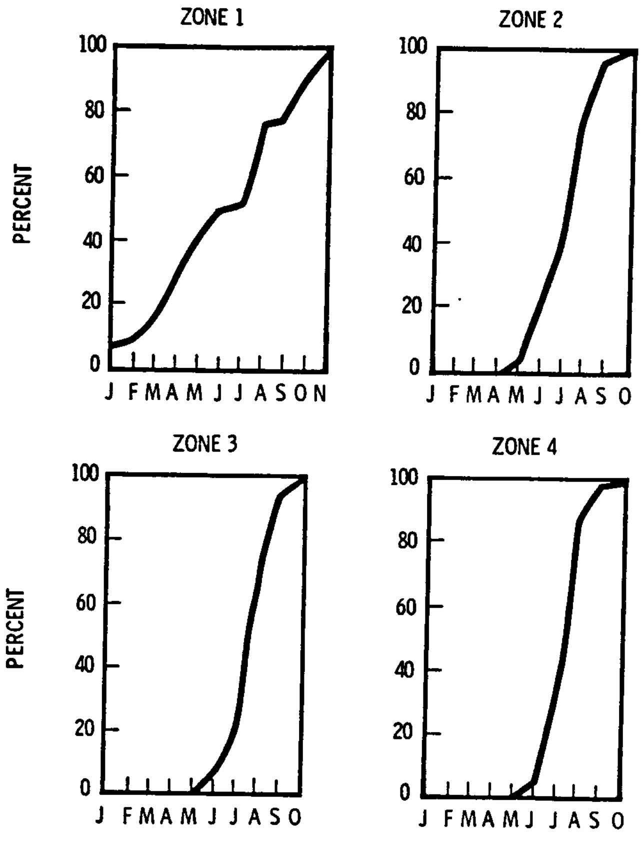


Figure 9.—The monthly values as a percentage of R for zones I, 2, 3, and 4 of Davis County experimental watershed, Utah.

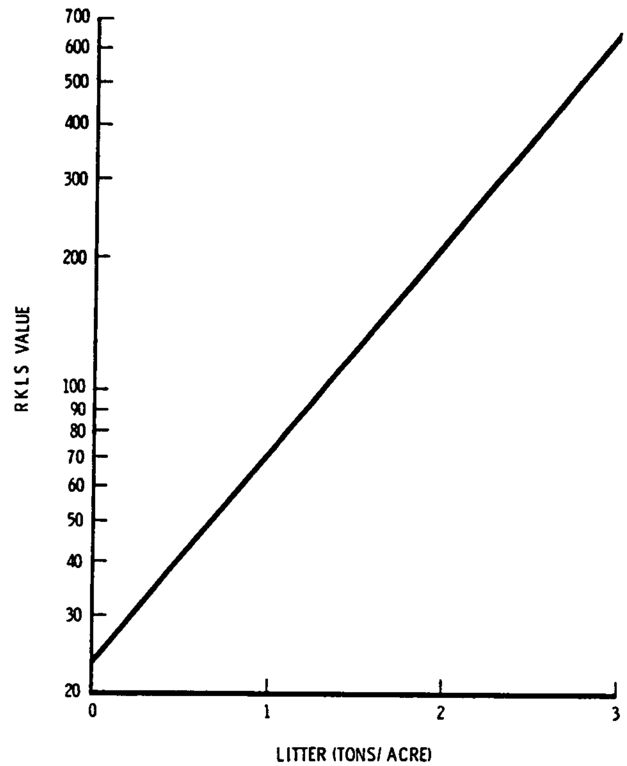


Figure 10.—The relationship between RKLS and the tons per acre of litter.

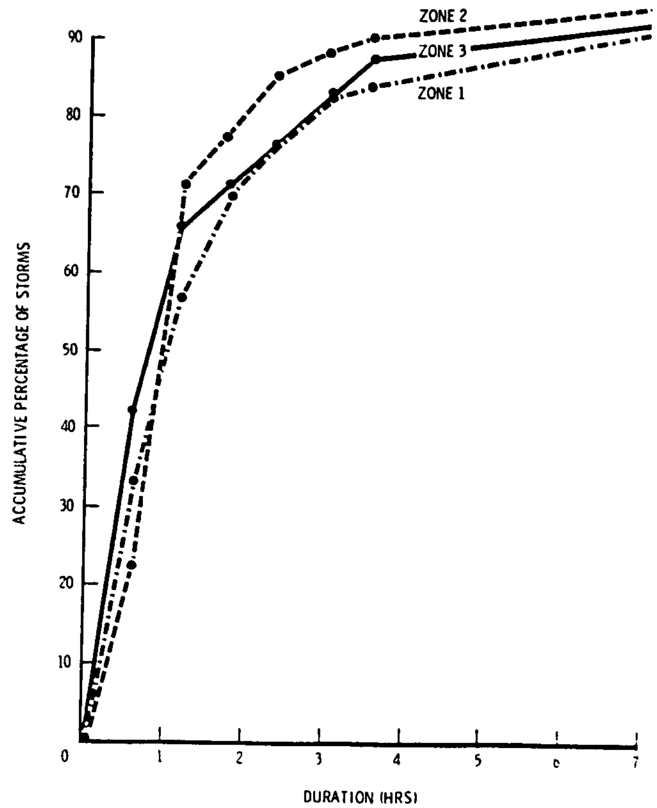


Figure 11.—The mass frequency distribution of storm duration in hours for zones 1, 2, and 3 of Straight Canyon barometer watershed, Utah.

the balance of the United States. Briefly, the method the mean annual erosion per acre, A, is equal to the product of R; an erodibility factor, K; a slope length factor, L; a slope steepness factor, S; and a cover practice parameter, CP.

The latter group also substituted VM for CP as more appropriate to nonfarm areas. The VM symbolizes vegetation management. All other treatments could be reduced to changing the values of slope or slope length, for example contour ditches, terraces, etc.

In the universal soil loss equation the values of L are in terms of the ratio of soil lost from a slope length of 72.6 feet (22 m) and the values of S are in terms of the ratio of the soil lost from a slope steepness of 9 percent gradient.

Example. A small homogeneous (soil, cover, and slope) area rectangular in shape has a slope length of 73 feet (22.3 m) and a gradient of 9 percent. There is 1 ton per acre (2.25 t/ha) of litter on the surface of the soil whose erodibility is 0.50. Is this sufficient protection to have less than 4 tons per acre (9 t/ha) of erosion if a 10-year event should occur? The R value is 31 and the R_{10}/R_2 is 8. Figure 10 shows the tons per acre (t/ha) of tter as related to the RKLS value that the mulch can vithstand without failure or appreciable erosion.

Solution. Enter figure 10 with 1 ton/acre (2.25 t/ha) and read RKLS = 74. This is the RKLS the litter can safeguard if the VM value is 1.0.

The 10-year RKLS of the site may be determined as follows:

R = 31 × 8 = 248
K = 0.50
LS = 1
RKLS = 248 × 0.50 × 1.0 = 124

124 > 74; therefore this amount of litter will not protect the site if the litter is the only protection the site has. If in addition to the 1 ton per acre (2.25 t/ha) of litter, there is a 10 percent ground cover of grass and a 50 percent canopy of tall weeds, this would make the VM factor equal to 0.19, figure 11. The site RKLS would reduce VM to 0.19 × 124 = 23.6, thus fully protecting the site from the 10-year R.

R values have other uses. For example, suppose we needed the 10-year runoff peak from a 1-square-mile watershed whose difference in elevation between the top and bottom of the watershed was 1,000 ft (305 m) and the R value at the watershed center was 30, the equation developed by Fletcher and others (1977) could be used as follows:

$$\hat{q}_{10} = 1.28015\ A^{0.56172}\ R^{0.94356}\ (DH)^{0.16887}$$

The desired 10-year peak flow would then be

$$\hat{q}_{10} = 1.28015\ (1)^{0.56172}\ (30)^{0.94356}\ (1000)^{0.16887}$$
$$= 101.8\ ft^3/S\ (2886\ liters/sec).$$

Storm Occurrence by Storm Duration

The percentage of short durations is appreciably higher on the Straight Canyon zones than either at the Davis County experimental watersheds or the Ephraim experimental area. Figure 11 shows the cumulative frequency distribution of storm durations. The correlation between elevation and duration can be seen in the mean values for each zone where zone 1 mean elevation 9,045 ft (2 757 m) has 33 percent of the storms shorter than 36 minutes, zone 2 mean elevation 10,065 ft (3 068 m) has 22 percent of the storms shorter than 36 minutes, and zone 3 elevation 7,765 ft (2 367 m) has 41 percent of the storms shorter than 36 minutes. Incidentally, only one storm at one location lasted up to 15 hours.

STORM DURATION The duration distribution of the 1,228 storm events on the Straight Canyon barometer watershed are shown in figure 12. The longest duration recorded for any storm was 15 hours, with 90 percent of the storms having durations shorter than 5 hours and approximately half of the storms having durations shorter than 1 hour.

STORM DEPTHS The largest single storm depth was 1.50 in (38 mm). Figure 13 shows the frequency districution of the 1,228 storm depths. Note that more than 65 percent of the storms have depths smaller than 0.15 in (3.8 mm). The depth distribution of storms at Straight Canyon essentially fits a log normal distribution as evidenced by the straight line in figure 13.

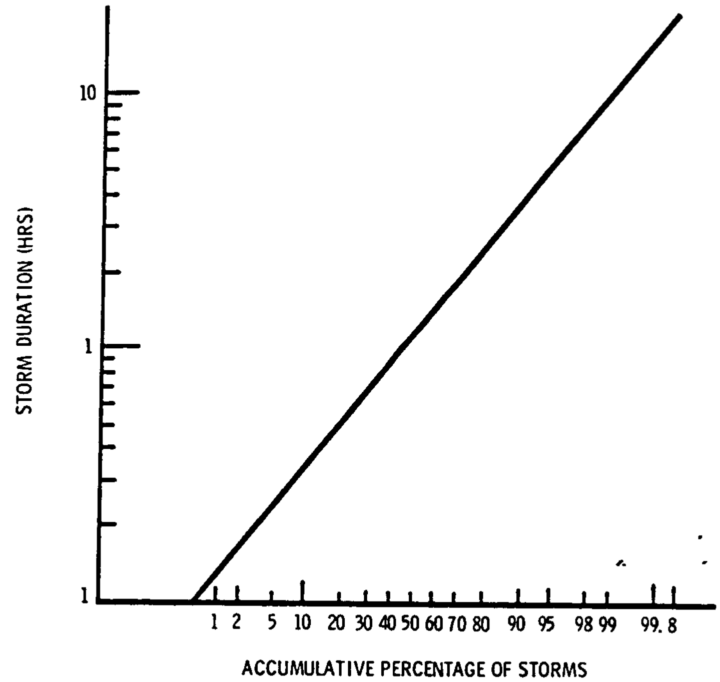


Figure 12.—The frequency distribution of durations of 1,228 storms on the Straight Canyon barometer watershed, Utah.

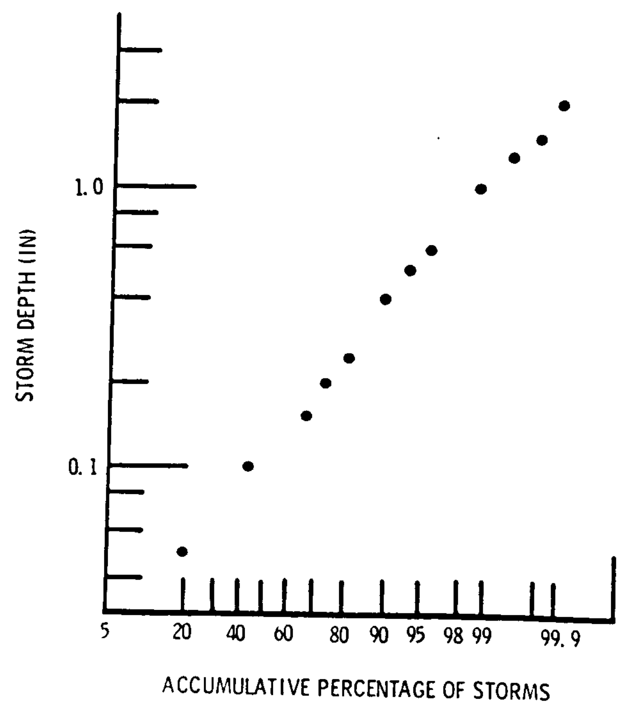


Figure 13.—The frequency distribution of storm depths for 1,228 storms on Straight Canyon barometer watershed, Utah.

DISCUSSION

In general, the mountain-valley intensity relationships stated by Brancato (1942) hold true for these data. He stated:

> With regard to variation of thunderstorm rainfall with elevation ... over a long period of time a station located at a lower elevation is likely to experience the most intense thunderstorm.

Dorroh (1946) also substantiates this hypothesis.

Plant cover destruction resulting in active flood and sediment source areas has occurred prevalently on high-elevation herbaceous sites that lie above the aspen-fir type, and was due primarily to summer grazing overuse by livestock. Our data show that the rainfall intensities expected to occur on such sites are quite substantial.

Some of the rainfall intensities that can be expected to occur probably will be greater than the infiltration capacities of some sites, particularly those in poor hydrologic condition. Hence, overland flow is almost a certainty. Fortunately, management practices on mountain watersheds can drastically alter runoff volumes, flood peaks, and erosion. This has been amply and convincingly demonstrated on the Davis County experimental watershed (Bailey and others 1934; Bailey and others 1947). On both study areas in the middle 1930's, severe mudrock floods were generated by storm events with a recurrence interval of only 15 years. Since that time, both vegetal and mechanical rehabilitation measures have resulted in the satisfactory disposition of storm rains of equal or greater magnitude.

The greatest annual rainfall intensities can be expected at the lowest elevation on the Straight Canyon barometer watershed. This is different than on the Ephraim side of the mountain but similar values were obtained at Oaks climate station, which is the same elevation band as zone 3 on Straight Canyon.

Depth-duration curves suggest that the longer the storm, the greater the runoff. Osborn (1964) has pointed out that the use of depth-duration data can result in misleading runoff values. He reported that, in the semiarid Southwest rangeland, major runoff events are often the result of short-lived, high-intensity convective storms. Osborn's conclusion is generally applicable to our study areas. Major amounts of summer runoff will usually come from storms of medium duration, namely 2 to 6 hours, with short periods of high-intensity rainfall bursts.

The slope of the depth duration curves of Straight Canyon all lie within the range of values found on the Great Basin experimental area.

Elevation significantly affects 10-minute, 10-year precipitation intensity at Straight Canyon and Great Basin but not on the Davis County area. Precipitation intensity decreases more than an inch per hour as elevation increases 5,000 ft (1 524 m).

A better relationship exists between the 10-minute, 10-year precipitation and the miles of penetration from the Wasatch-Pavant front. This relationship has a coefficient of variation of about 60 percent on the Straight Canyon area, decreasing to 50 percent on the Great Basin area and becoming nonsignificant on the Davis County area.

Although the mountain-valley intensity relationships tended to follow Brancato's (1942) thesis that the lower lying stations receive the most intense rainfall, our data do not support his contention concerning the amount of rainfall. He stated:

> Three to four times as many thunderstorms occurred on the middle and upper windward slopes of the mountains as on the relatively flat and lower portions of the basin. However, contrary to published and popular accounts, the thunderstorms produced the greatest amount of precipitation at the lower elevations and not on the mountain slopes. The most favorable conditions for the production of heavy rain is the presence of an air mass with a sufficient amount of available energy and the greatest possible amount of moisture. Orographic lifting is very effective as a mechanism to release the latent energy in an air mass, but as the air is lifted over progressively higher terrain, the total amount of available precipitable water above any given area becomes progressively smaller.

Two assumptions upon which Brancato bases his thesis might be questioned. One is the assumption that the amount of precipitable water in an airmass becomes significantly less as it is forced over a single mountain crest. It is not likely that the total precipitable water changes very much on adjacent precipitation zones. Significant diminution of precipitable water requires the passage of an airmass over substantial sections of terrain. Another questionable assumption is that orographic lifting is the dominant mechanism triggering storms. Orographic effects may well contribute to summer shower activity, but the local daytime slope heating and induced upslope breezes are probably more important. Cold fronts and upper troughs may also contribute to some of the storms, especially early and late in the season. These may act in conjunction with daytime surface heating and orographic lifting.

The relation between elevation and number of storms is similar to that between elevation and average monthly rainfall depth. The ratio between the number of storm occurrences at the highest zones and at the lowest zones varies between 1.0 and 1.2.

The Straight Canyon 60-minute rainfall intensities are more like those given by Farmer and Fletcher (1971) for southern Utah than central Utah. Other observations regarding area of application are similar.

On the basis of the zonal R values, both erosion and runoff peaks should be about 1.3 times as great in zone 3 as in zone 1.

PUBLICATIONS CITED

Bailey, Reed W., C. L. Forsling, and R. J. Becraft.
1934. Floods and accelerated erosion in northern Utah. U.S. Dep. Agric. Misc. Publ. 196, 21 p. Washington, D.C.

Bailey, Reed W., G. W. Craddock, and A. R. Croft.
1947. Watershed management for summer flood control in Utah. U.S. Dep. Agric. Misc. Publ. 639, 24 p.

Brancato, G. N.
1942. The meteorological behavior and characteristics of thunderstorms. U.S. Dep. Comm., Weather Bureau, Washington, D.C.

Chang, Tsing-Yuan.
1969. A study of precipitation characteristics for Utah. M.S. thesis. Utah State Univ., Logan. 85 p.

Chow, V. T.
1953. Frequency analysis of hydrologic data with special application to rainfall intensities. Univ. Ill. Eng. Exp. Stn. Bull. 414, 80 p.

Chow, V. T.
1964. Handbook of applied hydrology, a compendium of water resources technology, sect. 8, p. 29. McGraw-Hill Book Co., New York.

Croft, A. R., and R. B. Marston.
1950. Summer rainfall characteristics in northern Utah. Am. Geophys. Union trans. 31(1):83-95.

Croft, A. R., and R. W. Bailey.
1964. Mountain water. 64 p. USDA For. Serv., Intermt. Reg., Ogden, Utah.

Dorroh, J. H., Jr.
1946. Certain hydrologic and climatic characteristics of the Southwest. Univ. New Mexico Publ. 1, 54 p.

Farmer, Eugene E., and Joel E. Fletcher.
1971. Precipitation characteristics of summer storms at high elevations in Utah. USDA For. Serv. Res. Pap. INT-110, 24 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Farmer, Eugene E., and Joel E. Fletcher.
1972a. Rainfall intensity-duration-frequency relations for the Wasatch Mountains of northern Utah. Water Resour. Res. 8(1):266-271.

Farmer, Eugene E., and Joel E. Fletcher.
1972b. Some intra-storm characteristics of high intensity rainfall bursts. Proc. Symp. on Distribution of Precipitation in Mountainous areas, Geilo, Norway. p. 525-531.

Fletcher, Joel E., A. Leon Huber, Frank W. Haws, and Calvin C. Clyde.
1977. Runoff estimates for small rural watersheds and development of a sound design method. Federal Highway Administration Rep. No. FHWA-RD-77-158, 108 p.; -159, 336 p.; and -160, 222 p. Washington, D.C.

Hales, John E., Jr.
1972. Surges of maritime tropical air northward over the Gulf of California. Mon. Weather Ref. 100(4): 298-306.

Hales, John E., Jr.
1973. Southwestern United States summer monsoon source—Gulf of Mexico or Pacific Ocean. NOAA Tech. Memo NWS WR84, 26 p.

Miller, J. R., R. H. Frederick, and R. J. Tracy.
1973. Precipitation frequency atlas of the Western United States, vol. 6, Utah. NOAA Atlas No. 2, 67 p.

Orr, Howard K.
1957. Effects of plowing and seeding on some forage production and hydrologic characteristics of a subalpine range in central Utah. Res. Pap. 47, 23 p. Intermt. For. and Range Exp. Stn., Ogden, Utah.

Osborn, H. B.
1964. Effect of storm duration on runoff from rangeland watersheds in the semiarid southwestern United States. Int. Assoc. Sci. Hydrol. Bull. 4:40-47.

Packer, P. E.
1951. An approach to watershed protection criteria. J. For. 49:639-744.

Packer, P. E.
1963. Soil stability requirements for the Gallatin elk winter range. J. Wildl. Manage. 27(3):401-410.

Peck, E., and M. J. Brown.
1962. An approach to the development of isohyetal maps for mountainous areas. J. Geophys. Res. 64(2):681-694.

Price, R., and R. B. Evans.
1937. Climate of the west front of the Wasatch Plateau in central Utah. Mon. Weather Rev. 65(8): 291-301.

Searcy, J. K., and C. H. Hardison.
1960. Double-mass curves, manual of hydrology, part 1, general surface-water techniques. U.S. Geol. Surv. Water-Supply Pap. 1541-B, 66 p.

U.S. Weather Bureau.
1964. State of Utah normal annual and normal May-September precipitation isohyetal. Map distributed by Utah State Engineers Office, Salt Lake City, Utah.

Utah Water Research Laboratory and Intermountain Forest and Range Experiment Station.
1976. Erosion control during highway construction. Vol. 2, manual of erosion control principles and practices. 163 p.

Wischmeier, W. H., and D. D. Smith.
1958. Rainfall energy and its relation to soil loss. Trans. Am. Geophys. Union 39(2):285-291.

U.S. GOVERNMENT PRINTING OFFICE 1981—777-038/94 REGION NO. 8

Fletcher, Joel E., A. Leon Huber, Eugene E. Farmer, Keith R. McLaughlin, John Rector, and Larry J. Schmidt.

1981. Precipitation characteristics of summer storms at Straight Canyon barometer watershed, Utah. USDA For. Serv. Res. Pap. INT-274, 11 p. Intermt. For. and Range Exp. Stn., Ogden, Utah 84401.

Straight Canyon barometer watershed was divided into three similar precipitation intensity zones. The 50-year precipitation intensity (2-minute duration) increased from about 4 in (102 mm) per hour on zone 1, to about 13 in (330 mm) per hour on zone 3. Daily precipitation depths were revised, with zone 3 receiving 91.97 in (50 mm) and zone 1, 2.08 in (53 mm). Rainfall erosivity (R) increased from 12.5 hundreds of foot-tons per acre-inch (3.375 hundreds of t/ha-cm) in zone 1, to 16.7 hundreds of foot-tons per acre-inch (4.51 hundreds of t/ha-cm) in zone 3.

KEYWORDS: mountain precipitation, rainfall intensity, rainfall erosivity, rainfall time, rainfall duration

The Intermountain Station, headquartered in Ogden, Utah, is one of eight regional experiment stations charged with providing scientific knowledge to help resource managers meet human needs and protect forest and range ecosystems.

The Intermountain Station includes the States of Montana, Idaho, Utah, Nevada, and western Wyoming. About 231 million acres, or 85 percent, of the land area in the Station territory are classified as forest and rangeland. These lands include grasslands, deserts, shrublands, alpine areas, and well-stocked forests. They supply fiber for forest industries; minerals for energy and industrial development; and water for domestic and industrial consumption. They also provide recreation opportunities for millions of visitors each year.

Field programs and research work units of the Station are maintained in:

Boise, Idaho

Bozeman, Montana (in cooperation with Montana State University)

Logan, Utah (in cooperation with Utah State University)

Missoula, Montana (in cooperation with the University of Montana)

Moscow, Idaho (in cooperation with the University of Idaho)

Provo, Utah (in cooperation with Brigham Young University)

Reno, Nevada (in cooperation with the University of Nevada)

This page is a reference page used to track documents internally for the Division of Oil, Gas and Mining

Mine Permit Number M0350015 Mine Name KUC Tailing T
Operator Kennecott Utah Copper Date 2-7-1994
TO ______ FROM ______

__CONFIDENTIAL __BOND CLOSURE __LARGE MAPS X EXPANDABLE
__MULTIPUL DOCUMENT TRACKING SHEET __NEW APPROVED NOI
__AMENDMENT _OTHER______

Description YEAR-Record Number

__NOI X Incoming __Outgoing __Internal __Superceded

Precipitation Characteristics of Summer storms at Straight Canyon Barometer watershed, Utah

__NOI __Incoming __Outgoing __Internal __Superceded

__NOI __Incoming __Outgoing __Internal __Superceded

__NOI __Incoming __Outgoing __Internal __Superceded

__TEXT/ 81/2 X 11 MAP PAGES __11 X 17 MAPS __LARGE MAP

COMMENTS: ______

CC: ______

This page is a reference page used to track documents internally for the Division of Oil, Gas and Mining

Mine Permit Number M0350015 Mine Name KUC Tailing T

Operator Kennecott Utah Copper Date 2-17-1994

TO ______ FROM ______

__CONFIDENTIAL __BOND CLOSURE __LARGE MAPS X EXPANDABLE

__MULTIPUL DOCUMENT TRACKING SHEET __NEW APPROVED NOI

__AMENDMENT _OTHER ______

Description YEAR-Record Number

__NOI X Incoming __Outgoing __Internal __Superceded

Precipitation Characteristics of Summer storms at Straight Canyon Barometer Watershed, Utah

__NOI __Incoming __Outgoing __Internal __Superceded

__NOI __Incoming __Outgoing __Internal __Superceded

__NOI __Incoming __Outgoing __Internal __Superceded

__TEXT/ 81/2 X 11 MAP PAGES __11 X 17 MAPS __LARGE MAP

COMMENTS: ______

CC: ______